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**Department of**

## OCEANOGRAPHY AND METEOROLOGY

*Research Conducted through the*

*Texas A & M Research Foundation*

COLLEGE STATION, TEXAS

# RESEARCH ON TROPICAL RAINFALL PATTERNS AND ASSOCIATED MESO-SCALE SYSTEMS

**Report Nr. 2**

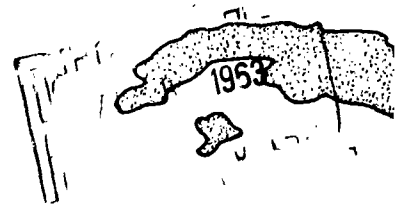
Electronics Contract Number DA-36-039 SC-89202

DEPARTMENT OF THE ARMY PROJECT Nr. 3A99-27-005-09

Second Quarterly Progress Report

1 September 1962 to 31 December 1962

A. and M. Project Nr. 311
Reference 62-21-T
25 March 1963




U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey

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# RESEARCH ON TROPICAL RAINFALL PATTERNS AND ASSOCIATED MESO-SCALE SYSTEMS

Report Nr. 2

Electronics Contract Number DA-36-039 SC-89202

Signal Corps Technical Guidelines for

P.R. & C. 62-ELS/R-1526 dated 20 December 1961

Department of the Army Project Nr. 3A99-27-005-09

U. S. Army Electronics Research and Development Laboratory

Second Quarterly Progress Report

1 September 1962 to 31 December 1962

The objective of this study is to obtain information on, and understanding of, meso-scale rainfall patterns in the Tropics. The work, at present, is concentrating on the Central American area.

Report Prepared by

John F. Griffiths

and

Walter K. Henry

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## OBJECTIVES OF THIS RESEARCH

The objectives of this research are as follows:

A. To identify the different sub-regions of meso-scale rainfall patterns.

B. To obtain information for locating new stations which will give a better understanding of the rainfall system movements.

C. To determine orographic effects on meso-scale rainfall patterns.

D. To investigate any singularities of rainfall which are encountered in the data.

ABSTRACT

A successful data gathering trip into Central America yielded a large volume of rainfall information. This included daily, monthly, and annual data for a large number of stations. Statistical analysis of the monthly data for El Salvador has been initiated. Meso-scale analysis of daily rainfall is attempted.

## LECTURES

Mr. Griffiths and Mr. Henry presented a lecture to the College Station Chapter of the American Meteorological Society.

Title: Progress and Aims of Project 311

Place: College Station, Texas

Date: December 4, 1962

## REPORTS

Title: Research on Tropical Rainfall Patterns and Associated Meso-Scale System Movements. First Quarterly Progress Report, 10 September 1962, John F. Griffiths and Walter K. Henry.

## CONFERENCES

On September 2, 1962, Mr. Griffiths, Mr. Cobb, and Mr. Henry departed for a two week data gathering trip to Central America. The trip was most successful. A short resume of the people visited and the data collected follows.

September 3 - San Salvador, El Salvador, Ing. Helmut Lessmann, Director Del Servicio Meteorologico Nacional. Ing. Lessmann had collected monthly and annual totals of rainfall for 130 stations for up to about 50 years. Some 45 of these stations have more than 10 years of data. He was most helpful in arranging for copies of this fine collection of data to be made available for the Project.

September 4 - Canal Zone, Mr. T. C. Henter, Hydrographic Office, Panama Canal Company; Major Kneid, Assistant Signal Officer, Caribbean Command; Major George A. Lockhart, Jr., Commander Det. 17, 15th Weather Squadron, Howard A. F. B.: Obtained monthly and annual data for 65 stations of at least 10 years duration, some stations having continuous records for 85 years. The CPS-9 radar pictures, taken at Albrook A. F. B., were made available to us, along with the daily maps. These are on a loan basis. All the persons listed above showed interest in the project and were extremely cooperative.

CONFERENCES con't.

September 5 - Puerto Armuelles, Panama, Mr. Arthur C. Hamilton, Manager, Chirique Land Company; Mr. Boyd Quate, President, Weather Engineers Inc.; Mr. Loren W. Crow, Consulting Meteorologist: Obtained daily rainfall data for a closely spaced network of rainfall gages for a period of ten years. Mr. Crow and Mr. Quate have been working on similar problems. They were able to make several suggestions.

September 6 - Golfito, Costa Rica, Mr. Cambell, Assistant Manager, Chirique Land Company: Obtained ten years of daily rainfall data for a closely spaced network of stations. These data physically join the data obtained in Puerto Armuelles and give a total of approximately 100 stations, most of which are in an area of 10 by 20 miles.

September 7 - San Jose, Costa Rica, Mr. Gronblad, Manager, Bananera De Costa Rica; Dr. Elliot Coen, Director, Servico Meteorologico Nacional. Mr. Gronblad was very helpful and able to give us monthly and daily data from Port Limon area. Dr. Coen had a good supply of data, monthly and annual for about 135 stations, many having long time continuity, but satisfactory arrangements could not be made to obtain copies.

September 10- Tegucigalpa, Honduras, Sr. Santiago Chiez, Director General de Aeronautica Civil; Sr. Vicente Fernandez, Assistant

CONFERENCES con't.

Chief, Honduranian Weather Service. The Honduranian Weather Service was well organized and was producing maps and forecasts for all of Central America. They were doing excellent synoptic meteorology. Their climatic work was limited but they had assembled good rainfall data for about 140 stations. Thirty-five of these were for periods of more than 10 years, and they were most helpful in making the data available to us.

September 11- La Ceiba, Honduras, Mr. G. T. Feyling, Manager, Standard Fruit Company; Mr. R. N. Quast, Standard Fruit Company: Obtained daily rainfall data for eight years for the Standard Fruit plantations. These data were for about 20 stations along the Aguan River Valley. The Standard Fruit Company showed their interest in our project.

September 12- La Lima, Honduras, Mr. James Shelton, Chief of Operations, Chirique Land Company; Mr. Peter Stubbe; Dr. R. H. Stover, Assistant Director, Division of Tropical Research, United Fruit Company. All of this group were very cooperative and supplied four years of daily rainfall data for some 40 stations in the Ulua River Valley and some long term monthly data.

CONFERENCES, con't.

September 13- Guatemala City, Guatemala, Sr. Carlos E. Pinto, Agent Chirique Land Company. He was most cooperative and able to give us daily rainfall data for several years in the Motagua River Valley. The three river valleys are almost parallel and when combined make an excellent set of data. The President of the Republic announced an extra holiday which precluded more extensive data gathering in Guatemala and the national services were not approached.

September 13- Belize, British Honduras, Mr. Chopin: Obtained annual and monthly data for about fifteen stations of 8 years duration.

For the excellent cooperation of the people listed above, the authors express their deep thanks. In addition, the authors wish to express their appreciation to the Standard Fruit Company, and Mr. R. A. Holcombe and Mr. Joseph W. Montgomery of the United Fruit Company.

October 9 - Mr. Griffiths and Mr. Henry visited with Dr. Wilfried Portig and Dr. John Gerhardt of the University of Texas. Discussions concerning the project were stimulating.

October 22-27 Mr. Griffiths visited our sponsor. He had beneficial discussions with Mr. Marvin Lowenthal and with Dr. R. M.

CONFERENCES, con't.

Marchgraber. On the same trip he visited the data center at Ashville to search for usable data.

December 7 - Dr. Wilfried Portig, University of Texas, visited the project. He contributed several good suggestions as well as some choice data from Panama.

The authors are indebted to Dr. Portig and the U. S. Electronics Research and Development Laboratory for the excellent card index bibliography concerning tropical meteorology.

## WORK ACCOMPLISHED THIS PERIOD

### A. Data Collecting and Processing

Following the successful data collecting trip to Central America described previously in this report, came the task of organizing this volume of data. Most of the efforts of the persons employed were directed toward sorting and organizing the data. Some of the data had to be returned; therefore, it had to be copied. Other data were not arranged suitably for our purposes and had to be reorganized. This type of work consumed many man hours.

The monthly and annual rainfall data for El Salvador, Panama, Honduras, and British Honduras have been entered on punch cards. Certain programs have been run on the IBM 709 computer. These computations will be described later in this report. (Statistical analysis section)

Another requirement was for maps of the areas, this being especially true for the plantation areas where daily rainfall data were to be utilized for areal distribution. Maps on the scale of 1:500000 and on the scale of 1:250000 have been prepared. Stations have been located. Other maps of the same scale have been prepared showing the orographic features.

These maps are shown as Figures 1 thru 4.

Figure 1. The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the orographic features and political division.

Figure 2. The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the location of rain gages. The dots are United Fruit Plantations. The open circles represent cities and towns of the area.

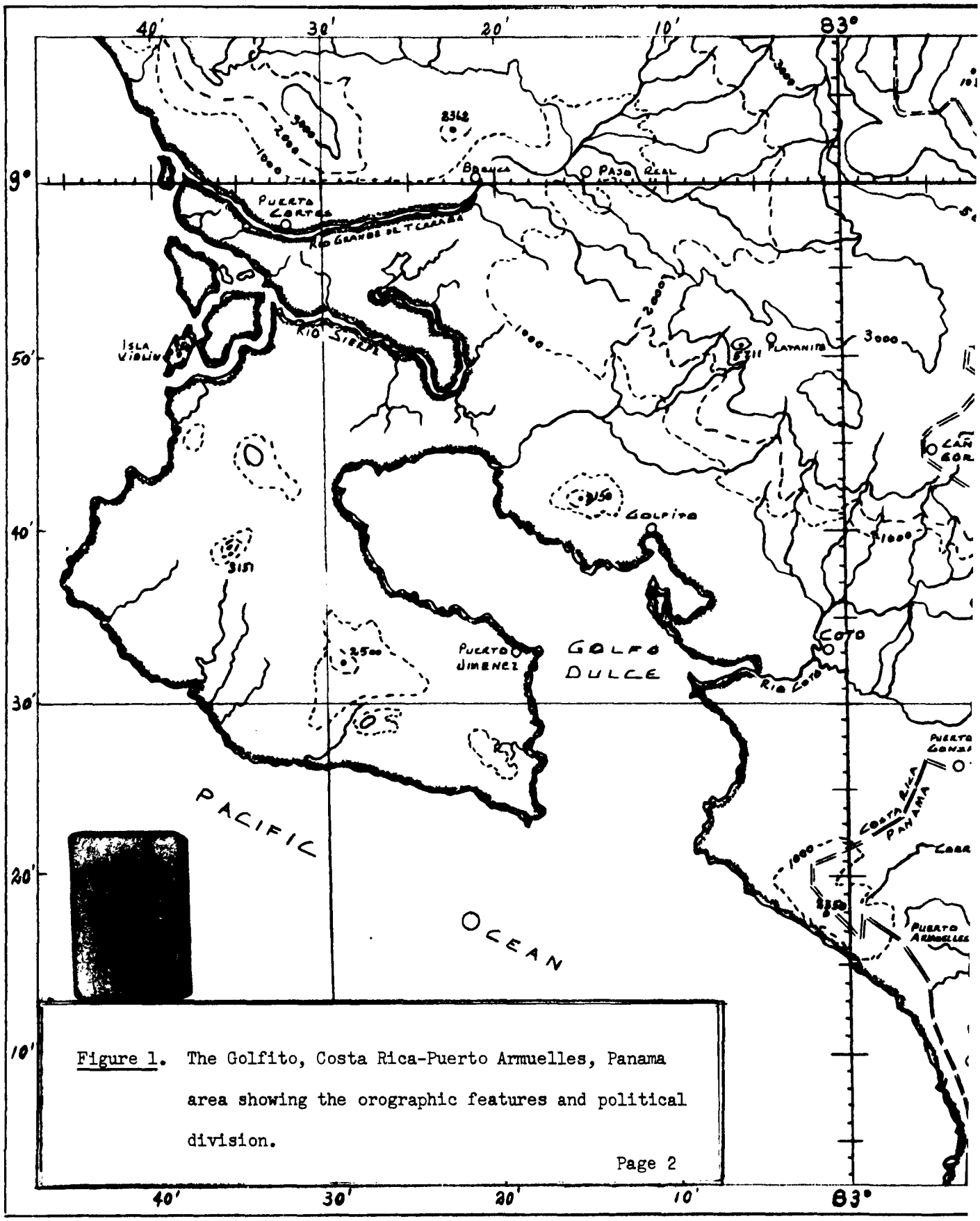
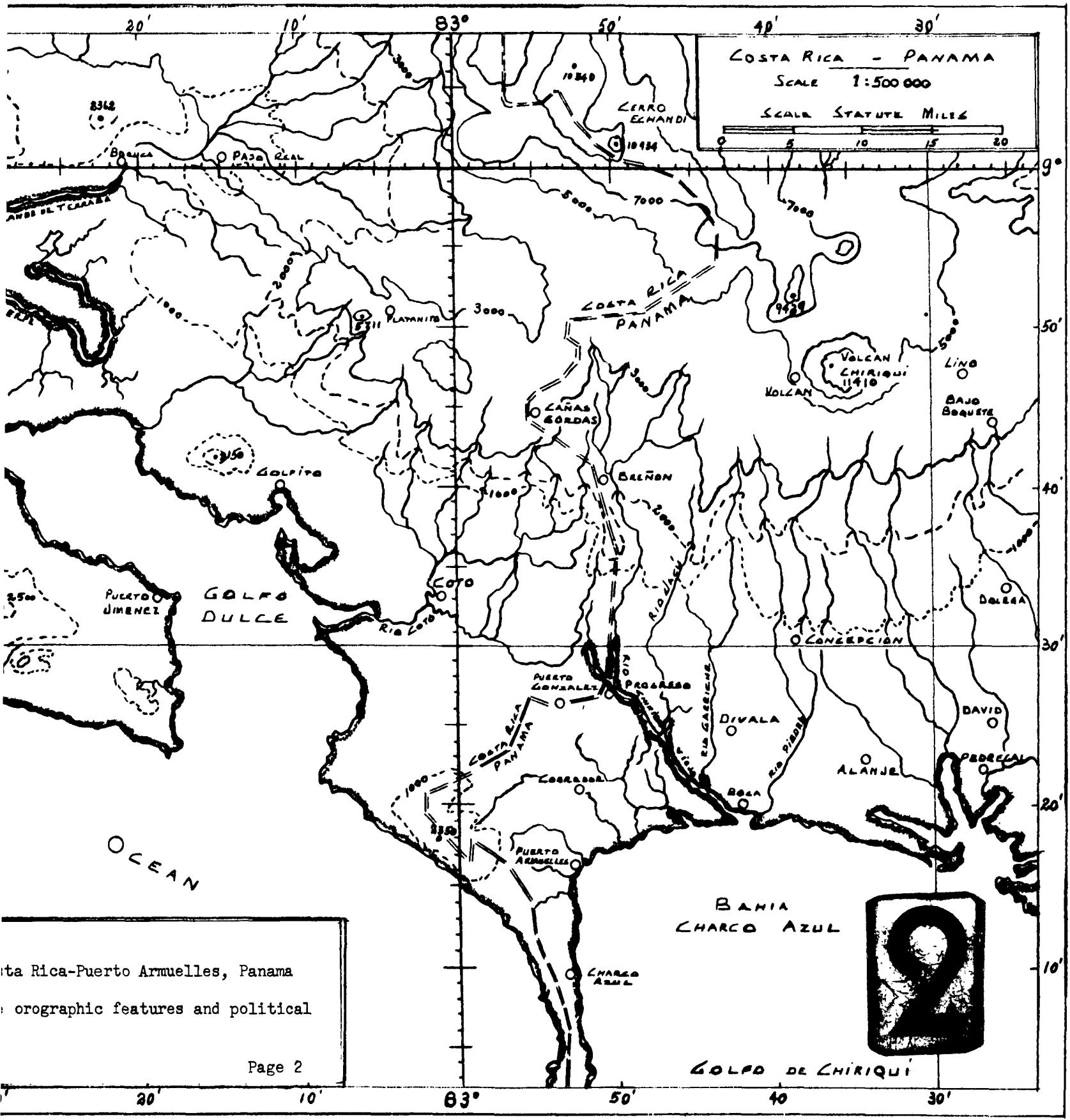



Figure 1. The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the orographic features and political division.




ıta Rica-Puerto Armuelles, Panama

: orographic features and political

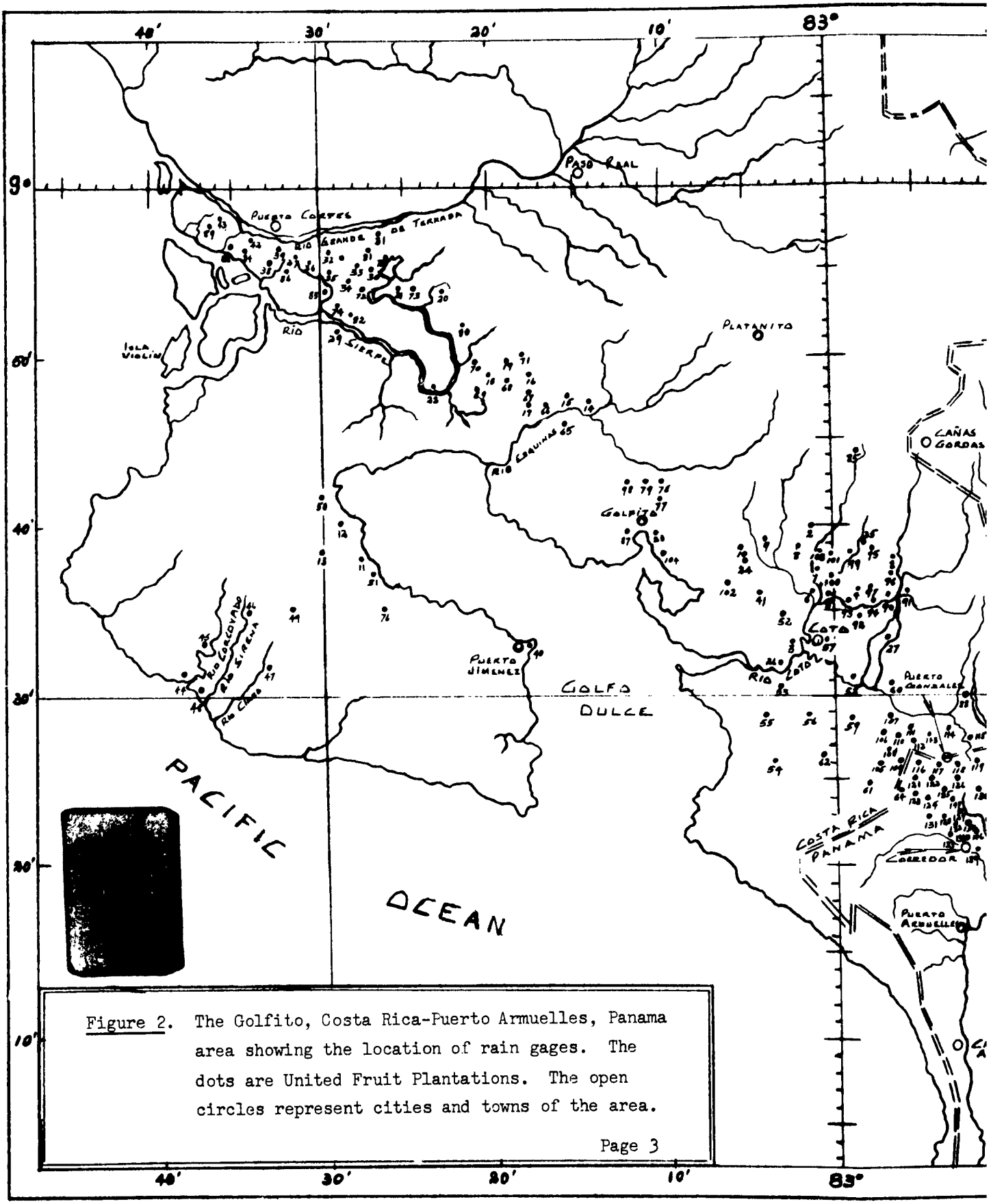
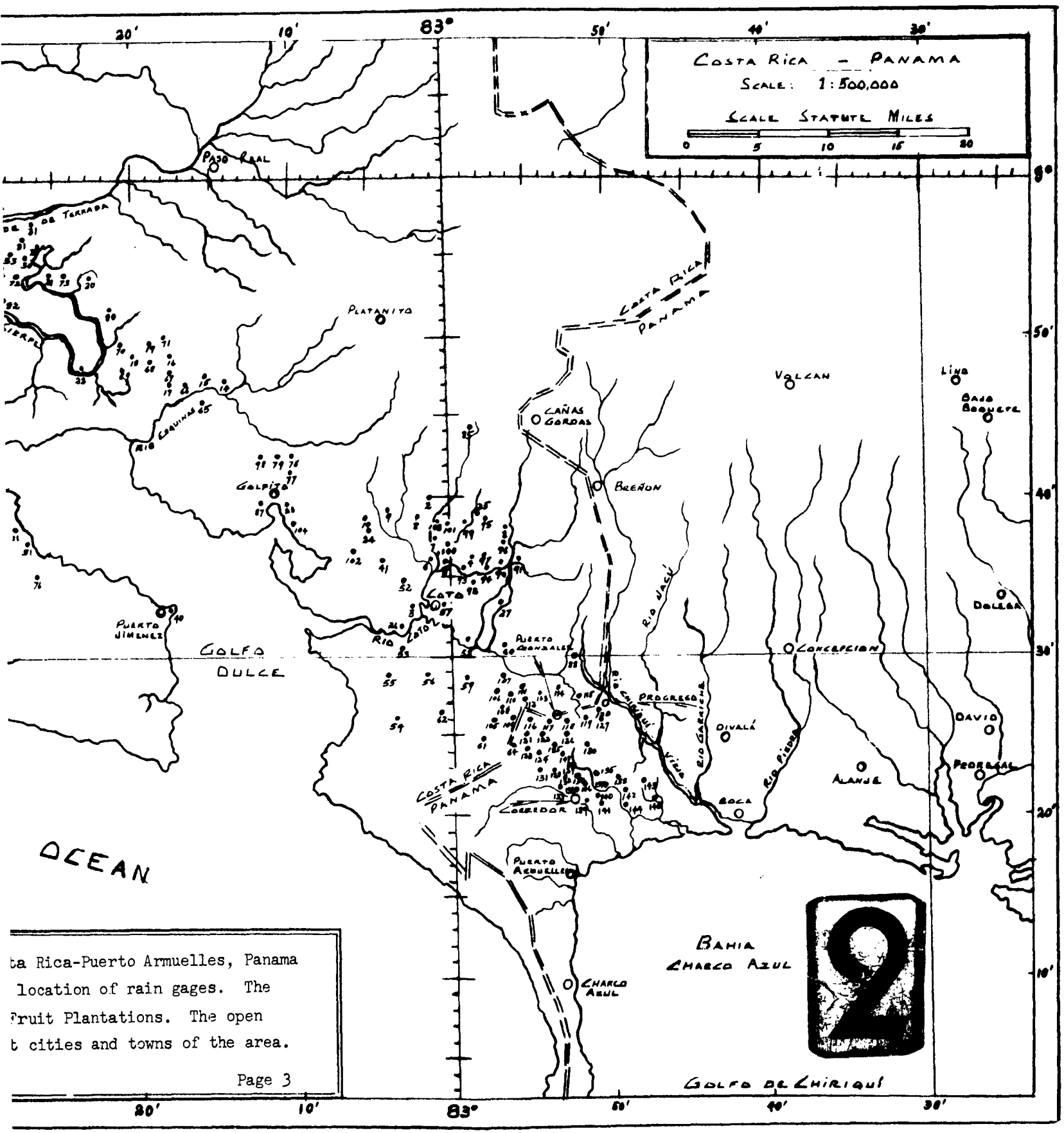



Figure 2. The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the location of rain gages. The dots are United Fruit Plantations. The open circles represent cities and towns of the area.




ta Rica-Puerto Armuelles, Panama
location of rain gages. The
Fruit Plantations. The open
t cities and towns of the area.

## Table I

Station Identifiers for Figure 2, the Golfito-Puerto Armuelles Area

| No. | Location | No. | Location |
|---|---|---|---|
| 1 | Corredor | 84 | Finca 17 |
| 2 | Caracol | 85 | Agua Buena |
| 23 | Golfito | 86 | Finca 15 |
| 25 | Administracion | 87 | Arboleda Golfito |
| 26 | Pueblo Nuevo | 90 | Finca 42 |
| 27 | Colorado | 91 | Finca 43 |
| 30 | Finca 6 | 92 | Finca 44 |
| 31 | Palmar Sur | 93 | Finca 47 |
| 32 | Finca 3 | 94 | Finca 45 |
| 33 | Finca 5 | 95 | Finca 49 |
| 34 | Finca 8 | 96 | Finca 41 |
| 35 | Finca 9 | 97 | Finca 46 |
| 36 | Finca 10 | 98 | El Alto |
| 37 | Finca 11 | 99 | Finca 48 |
| 38 | Finca 16 | 100 | Finca 50 |
| 41 | Coto Junta | 102 | Independientes |
| 50 | Rincon | 103 | Finca 54 |
| 52 | Quebrada Hedionda | 104 | Bolsa Golfito |
| 53 | Rio Conte Abajo | 105 | Naranjo |
| 54 | Rio Conte Arriba | 106 | Limon |
| 55 | Estero Sabalo | 107 | Caimito |
| 56 | Rio Incendio Boca | 108 | Cenizo |
| 57 | Quebrada Arena | 109 (63) | Roble |
| 58 | Km.25 Line F. C. Coto | 110 | Caucho |
| 59 | Km.28 Line F. C. Coto | 111 | Mango |
| 60 | Coronillo | 112 | Bambito |
| 61 | Rio La Vaca | 113 | Puerto Gonzalez |
| 62 | Rio Incendio Arriba | 114 | Jobo |
| 65 | Finca Limon | 115 | Peral |
| 66 | Finca Alajuela | 116 | Sigua |
| 67 | Finca Heredia | 117 | Balsa |
| 68 | Finca San Jose | 118 | Almendro |
| 69 | Finca Cartago | 119 | Chuchupate |
| 70 | Finca Guanacaste | 120 | Quira |
| 71 | Finca Puntarenas | 121 | Corozo |
| 72 | Finca 7 | 122 | Guayabo |
| 73 | Finca 18 | 123 | Canaza |
| 74 | Finca 13 | 124 | Bongo |
| 75 | Finca 1 | 125 | Higueron & Bogamani |
| 80 | Finca Jalaca | 126 | Palmito |
| 81 | Finca 2 | 127 | Maria |
| 82 | Finca 12 | 128 | Zapatero |
| 83 | Finca 14 | 129 | Blanco |

TABLE I con't.

| No. | Location |
|---|---|
| 130 | Caoba |
| 131 | Burica |
| 132 | Javillo |
| 133 | Majagua |
| 134 | Zapote |
| 135 | Jobito |
| 136 | Corredor |
| 137 | Jagua |
| 138 | Lechosa |
| 139 | Palo Blanco |
| 140 | Ceiba |
| 141 | Guayacan |
| 142 | Malagueto |
| 143 | Carana |
| 144 | Managa |
| 145 | Toroto |
| 146 | Nispero |

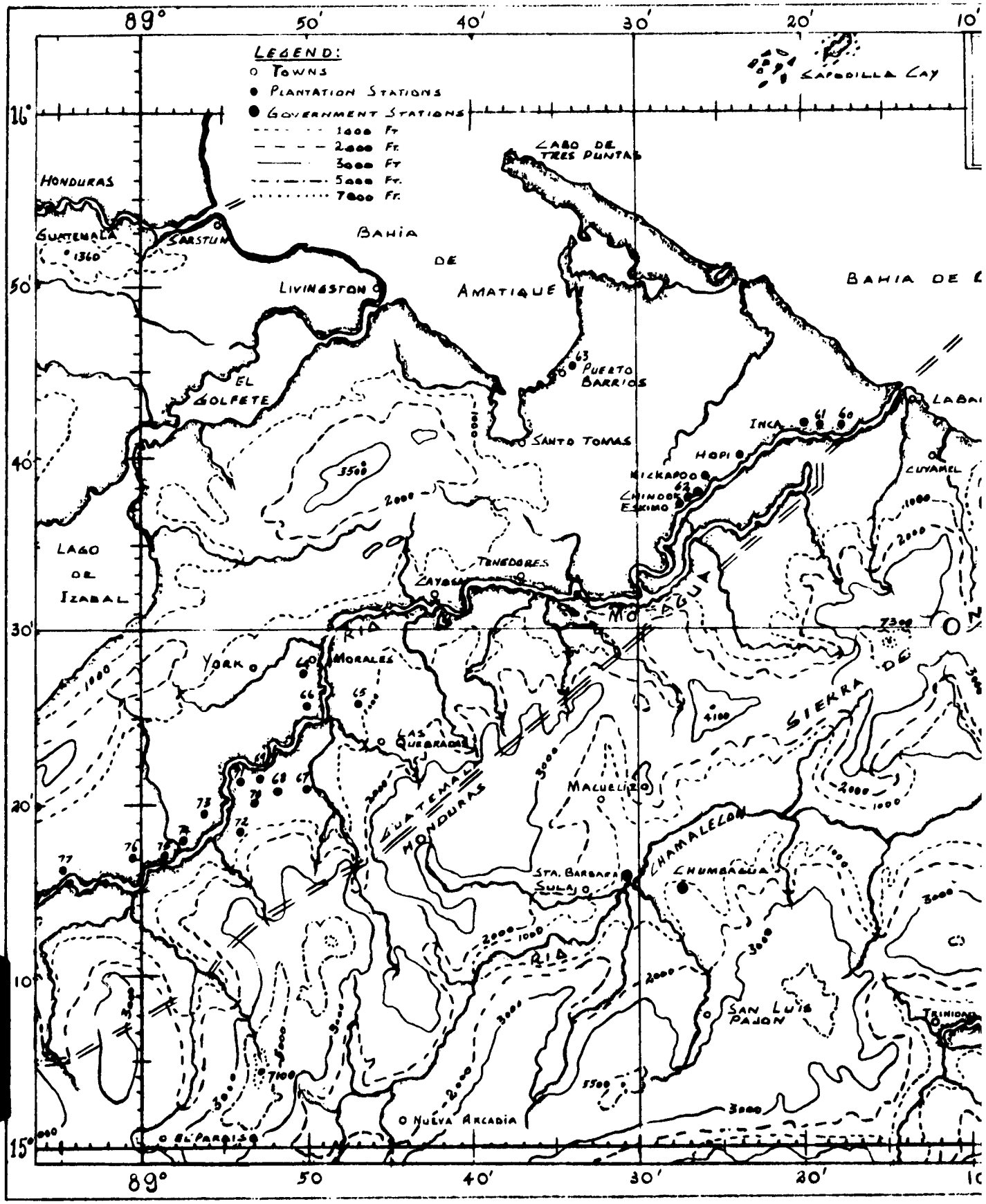
Figure 3. The Honduras-Guatemala area showing the orographic features and political divisions. The location of the rain gages, cities, and towns are identified. The plantations are owned and operated by the United Fruit Company.

Figure 4. The La Ceiba, Honduras area showing the orographic features and the location of the rain gages. The small solid circles are Standard Fruit plantations, the open circles are cities and towns while the large solid circles are stations reported by the Honduranian Weather Service.

Tables I and II identify the stations shown by numbers on Figures 2 and 3.

The La Ceiba area offers an excellent opportunity for investigations of rainfall variations with height. The ocean with inhabited islands offshore, a 8,000 foot mountain with a valley on the inland side are the existing features of terrain. The already established network of rain gages, the cooperative friendliness of both the Honduranian Weather Service, and the Standard Fruit Company make such a project feasible and desirable.

Because of the density of rain gages in some areas it is necessary to effect the analysis on a larger scale. A scale of 1:250000 has been found to be satisfactory.


LEGEND:
TOWNS
PLANTATION STATIONS
GOVERNMENT STATIONS
1000 FT
2000 FT
3000 FT
5000 FT
7000 FT
SAPODILLA CAY
CABO DE TRES PUNTAS
HONDURAS
GUATEMALA
SARSTUN
BAHIA DE AMATIQUE
LIVINGSTON
BAHIA DE
EL GOLFETE
PUERTO BARRIOS
SANTO TOMAS
INCA
HOPI
KICKAPOO
CHINDOK
ESKIMO
CUYAMEL
LAGO DE IZABAL
TENEDORES
CAYOSA
RIO MOTAGUA
YORK
MORALES
LAS QUEBRADAS
GUATEMALA
HONDURAS
MACUELIZO
SIERRA DE
CHAMALECON
STA. BARBARA
SULA
CHUMBAGUA
RIO
SAN LUIS PAJON
NUEVA ARCADIA
EL PARAISO
89°
50'
40'
30'
20'
10'
16°
15°

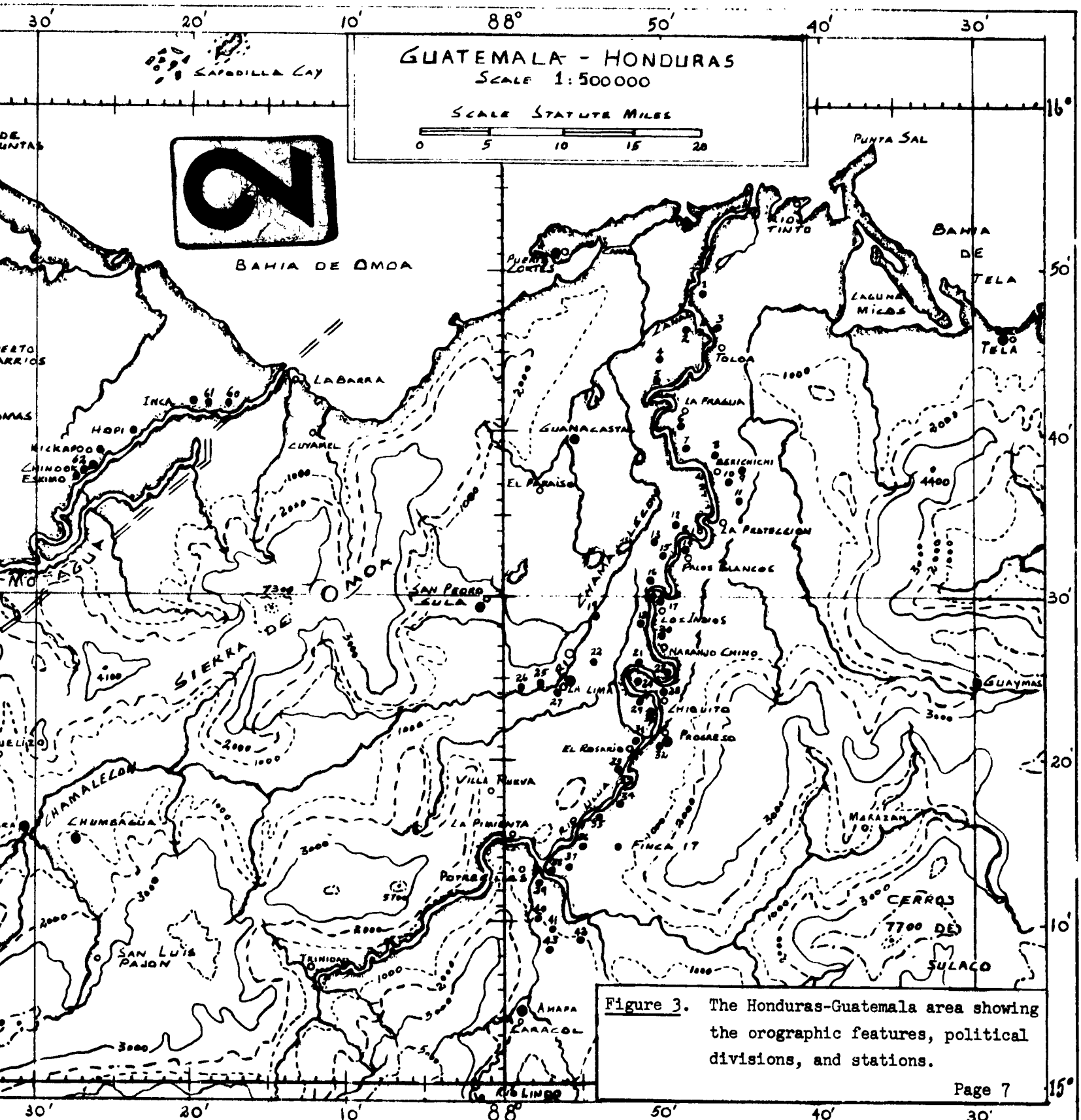
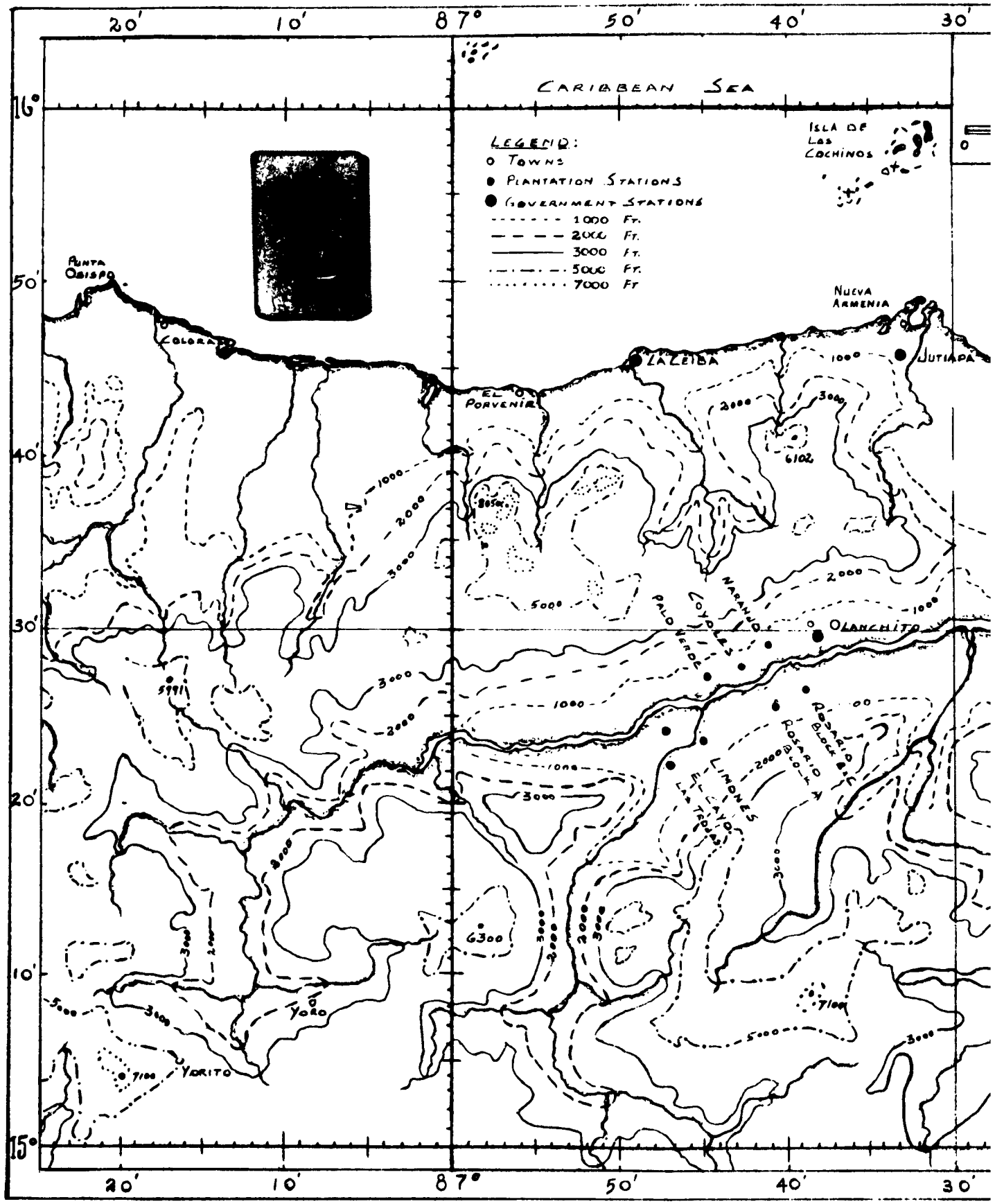

GUATEMALA - HONDURAS
SCALE 1:500000
SCALE STATUTE MILES
0 5 10 15 20
SAPODILLA CAY
BAHIA DE AMOA
PUNTA SAL
BAHIA DE TELA
LAGUNA MICOS
TELA
TOLOA
LA BARRA
INCA
HOPI
MICKAPOO
CHINOOK ESKIMO
CUYAMEL
GUANACASTA
LA PRAGUA
EL PARAISO
BERICHICHI
LA PROTECCION
PALOS BLANCOS
LOS INDIOS
NARANJO CHINO
LA LIMA
CHIQUITO
PROGRESO
EL ROSARIO
VILLA NUEVA
LA PIMIENTA
FINCA 17
MARAZAN
CERROS
SULACO
SAN PEDRO SULA
SIERRA DE OMOA
CHAMALECON
CHUMBAGUA
SAN LUIS PAJON
TRINIDAD
AMAPA
LARACOL
GUAYMAS
Figure 3. The Honduras-Guatemala area showing the orographic features, political divisions, and stations.

TABLE II

Station Identifiers for Figure 3, the Honduras-Guatemala Area

| No. | Location | No. | Location |
|---|---|---|---|
| 1 | El Tigre | 60 | La Barra & El Paraiso |
| 2 | Nispero | | |
| 3 | Melcher | 61 | Las Brisas |
| 4 | Calan | 62 | Media Luna |
| 5 | Guanacastal | 63 | Puerto Barrios |
| 6 | La Fragua | 64 | Bananera |
| 7 | Birichichi | 65 | Cerritos |
| 8 | Pavon | 66 | Oneida |
| 9 | Perdiz | 67 | Onondega |
| 10 | Paujil | 68 | Tikal - Sebol |
| 11 | Guaymas | 69 | Panajachel |
| 12 | Tibombo | 70 | Zaculeu - Lanquin |
| 13 | Lupo | 71 | Comanche |
| 14 | Monterrey | 72 | Arapahoe |
| 15 | Laurel | 73 | Patzum |
| 16 | Los Limones | 74 | El Pilar |
| 17 | Los Indios | 75 | Yuma |
| 18 | Indiana | 76 | Aztec |
| 19 | Tacamiche | 77 | Quirigua |
| 20 | Naranjo Chino | | |
| 21 | Mopala | | |
| 22 | San Juan | | |
| 23 | Santa Rosa | | |
| 24 | Cobb | | |
| 25 | Zapote | | |
| 26 | Guaruma | | |
| 27 | La Lima | | |
| 28 | Buena Vista | | |
| 29 | Monte Vista | | |
| 30 | Omohita | | |
| 31 | Campin | | |
| 32 | Progreso | | |
| 33 | Travesia | | |
| 34 | Finca 10 | | |
| 35 | Finca 11 | | |
| 36 | Finca 12 | | |
| 37 | Finca 18 | | |
| 38 | Finca 16 | | |
| 39 | Blanco | | |
| 40 | Higuerito | | |
| 41 | Barranco | | |
| 42 | Llano | | |
| 43 | Oliva | | |



CARIBBEAN SEA
LEGEND:
TOWNS
PLANTATION STATIONS
GOVERNMENT STATIONS
1000 FT.
2000 FT.
3000 FT.
5000 FT.
7000 FT
ISLA DE LOS COCHINOS
PUNTA OBISPO
COLORADO
EL PORVENIR
LA CEIBA
NUEVA ARMENIA
JUTIAPA
OLANCHITO
NARANJO
COYOLES
PALO VERDE
ROSARIO BLOCK B&C
ROSARIO BLOCK A
LIMONES
EL CAYO
LAS TROJAS
YORO
YORITO
6102
6300
7100
5991
20'
10'
87°
50'
40'
30'
16°
15°

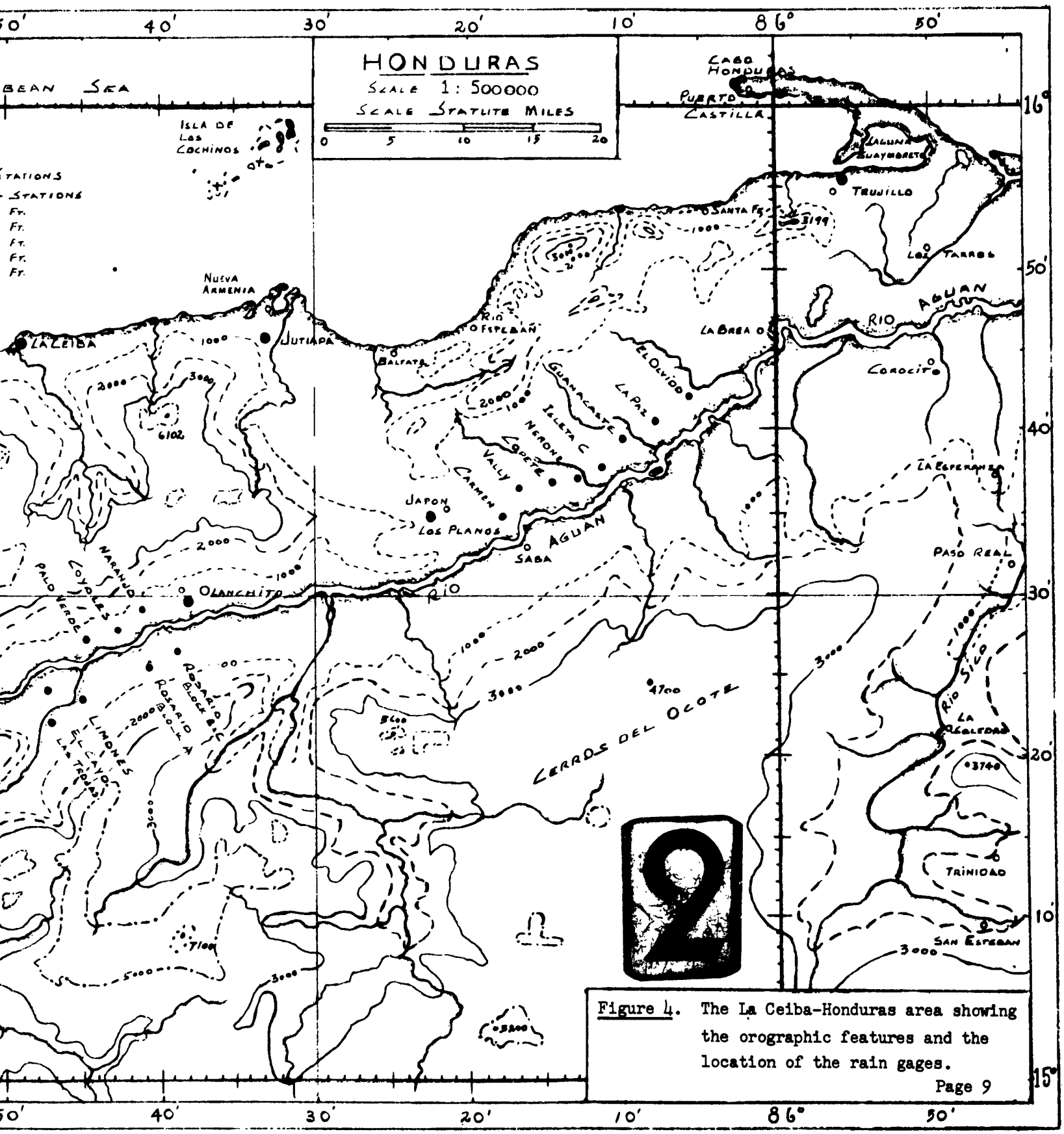



Figure 4. The La Ceiba-Honduras area showing the orographic features and the location of the rain gages.

B. Statistical Rainfall Analysis

In this preliminary areal investigation twenty stations in the western part of El Salvador have been selected. These stations comprise the only ones in that area for which there is a period of records of sufficient length to perform a statistical analysis.

The stations, with their identifying numbers, are as follows:

| | | | |
|---|---|---|---|
| 1 | San Jeronimo | 6 | Santa Lucia |
| 3 | Metapan | 7 | Santa Ana |
| 4 | Texis Junction | 8 | Coatepeque |
| 5 | Chalchuapa | 101 | Ahuachaplan |
| 102 | Atiquizaya | 304 | San Andres |
| 201 | Sonsonate | 308 | Santa Tecla |
| 202 | Acajulta | 309 | Comasagua |
| 301 | Tepecoyo | 501 | La Toma |
| 302 | Ateos | 502 | La Cabana |
| 303 | Sitio del Nino | 503 | Apopa |

The geographical locations of these stations are shown in Figure 5.

## ANALYSIS

The number of monthly and yearly observations available varied between 10 and 47, so that, even with the larger samples, it is permissible only to use the Cornu and the third moment (skewness) tests for the study of the normality of the distribution. The fourth moment (kurtosis) can be used only when the sample size is of the order of 100 or more.

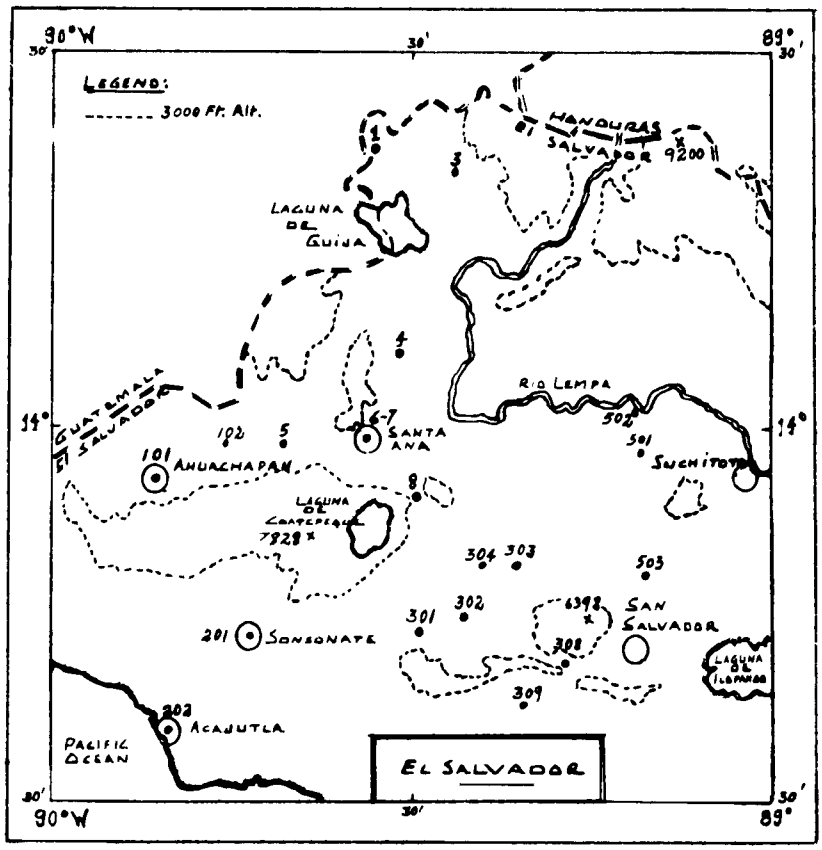



Figure 5.

Map of Western El Salvador Showing the Locations of the Chosen Twenty Stations.

The tests themselves, outlined in the First Quarterly Report of this project, are not given here but will appear, in detail, in the Final Report.

Using the punched cards prepared for the stations, a program has been run at the Data Processing Center of the A. & M. College on the IBM 709 which supplies the parameters of first, second, and third moments of groups of data, plus similar information concerning their square roots.

Annual Totals

Using the actual observed annual totals for each year at each station, it was shown by the tests that 18 of the 20 had distributions not significantly different from normal.

Therefore, for these 18 stations, it is allowable to use tables of the normal distribution to calculate the probability of not receiving, or of exceeding a certain amount of precipitation in a year. It is also possible to calculate the limits between which a given percentage of the annual totals should fall and this has been completed in Table III for the 50%, 80%, 90%, and 99% ranges. The two non-normal stations have been included for comparison. The values in parentheses are the observed percentages. These are omitted for the 99% range as the number of observations is insufficient to give such a value any real meaning.

Monthly Totals

As was explained in the First Quarterly Report, it is necessary here to consider the square roots of all the monthly totals, testing

TABLE III

Summary of Results and Calculated Ranges for Annual Totals of Rainfall

At the Chosen Twenty Stations

| Stn. | Res. | No. Yrs. | Mean | 50% range | 80% range | 90% range | 99% range | Observed Max. | Observed Min. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | N | 31 | 1464 | 1246-1682 (55) | 1045-1883 (78) | 928-2000 (87) | 620-2308 | 2159 | 921 |
| 3 | N | 31 | 1562 | 1321-1803 (58) | 1096-2028 (81) | 966-2158 (87) | 622-2502 | 2494 | 798 |
| 4 | N | 30 | 1758 | 1560-1956 (47) | 1380-2136 (78) | 1274-2242 (93) | 997-2519 | 2444 | 1194 |
| 5 | X | 33 | 1951 | 1677-2225 (52) | 1425-2477 (88) | 1277-2625 (91) | 891-3011 | 2669 | 1214 |
| 6 | N | 34 | 1990 | 1810-2170 (41) | 1645-2335 (74) | 1548-2432 (91) | 1294-2686 | 2419 | 1496 |
| 7 | N | 47 | 1707 | 1444-1970 (53) | 1202-2212 (81) | 1060-2354 (87) | 688-2726 | 2521 | 660 |
| 8 | N | 44 | 1774 | 1591-1957 (55) | 1424-2124 (75) | 1325-2223 (91) | 1068-2480 | 2347 | 1241 |
| 101 | N | 33 | 1916 | 1707-2125 (43) | 1516-2316 (82) | 1403-2429 (94) | 1109-2723 | 2706 | 1411 |
| 102 | N | 33 | 1787 | 1598-1976 (48) | 1425-2149 (85) | 1324-2250 (91) | 1057-2517 | 2586 | 1255 |
| 201 | N | 46 | 1912 | 1656-2168 (52) | 1421-2403 (76) | 1283-2541 (85) | 922-2902 | 2641 | 1206 |
| 202 | N | 47 | 1732 | 1520-1944 (49) | 1326-2138 (70) | 1212-2252 (94) | 914-2550 | 2347 | 1243 |
| 301 | N | 10 | 2004 | 1844-2164 (50) | 1694-2314 (70) | 1607-2401 (100) | 1380-2628 | 2333 | 1672 |
| 302 | N | 23 | 1548 | 1368-1728 (48) | 1204-1892 (74) | 1108-1988 (96) | 856-2240 | 2104 | 1133 |
| 303 | N | 25 | 1570 | 1402-1738 (44) | 1248-1892 (72) | 1157-1983 (96) | 920-2220 | 2021 | 1162 |
| 304 | N | 15 | 1711 | 1575-1847 (60) | 1449-1973 (73) | 1357-2047 (87) | 1183-2239 | 2075 | 1407 |
| 308 | X | 20 | 1880 | 1695-2065 (55) | 1525-2235 (95) | 1428-2332 (95) | 1165-2595 | 2697 | 1527 |
| 309 | N | 11 | 2054 | 1812-2296 (55) | 1589-2519 (82) | 1458-2650 (91) | 1117-2991 | 2388 | 1282 |
| 501 | N | 31 | 1927 | 1703-2151 (48) | 1497-2357 (77) | 1376-2478 (87) | 1061-2793 | 2659 | 1302 |
| 502 | N | 18 | 1758 | 1624-1892 (56) | 1501-2015 (72) | 1427-2089 (89) | 1237-2279 | 2122 | 1415 |
| 503 | N | 33 | 1958 | 1774-2152 (49) | 1605-2311 (85) | 1505-2411 (91) | 1246-2670 | 2742 | 1506 |

these for normality. For the twenty stations this gave a total of 240 months and of these 161 were identified as being not significantly different from normal.

It is clear, however, that months with a small average rainfall will generally have a large number of zeroes, thereby invalidating an assumption of normality due to a truncation effect.

Using a criterion deduced from this present analysis, it has been found that, if for the month the coefficient of variation ($\frac{100\ \sigma}{\bar{x}}$) for the square roots is less than 105, the month is likely to have a distribution not significantly different from the square root normal pattern. The actual analysis showed that of the 162 station-months with a coefficient of variation less than 105 there were 147 (91%) satisfying the normality tests. This percentage of success is identical with the 91% level found in the analysis of monthly totals of East African stations.*

The criterion concerning the coefficient of variation is roughly equivalent to stating that the monthly mean should exceed about 10mm or 0.4 inch.

Of the 24 months with a coefficient of variation of 200 or more, none was normally distributed.

The threshold level of 105 was obtained empirically being the value at which the percentage success value, which was always large, began to decrease. The position of the threshold may alter when the

*J. F. Griffiths. Proc. W.M.O./Munitalp Symposium on Tropical Meteorology, Nairobi, 1959.

full analysis is completed but is not expected to be outside the 100-110 range.

Table IV gives details of the results of comparing the coefficient of variation with the distribution, the normal months being underlined.

It also became clear from the analysis that as the monthly average rainfall increased the coefficient of variability, V, decreased and a graph of this is given in Figure 6. The graph shows that while it is possible to make a rough estimate of the coefficient of variation when $\bar{x}$ is known, the deduced value may be in appreciable percentage error for any one station-month.

In Table V are given the values of the 50%, 80%, 90%, and 99% ranges, together with the observed percentage for two months for all stations.

## TABLE IV

Coefficient of Variation for Each Station and Month

| Stn. | Month of Year 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 210 | 229 | 103* | 54 | 34 | 18 | 23 | 21 | 17 | 24 | 110 | 216 |
| 3 | 557 | 177 | 90 | 59 | 25 | 21 | 27 | 19 | 16 | 27 | 108 | 202 |
| 4 | 277 | 203 | 112 | 58 | 25 | 15 | 17 | 19 | 19 | 25 | 85 | 179 |
| 5 | 185 | 259 | 142 | 86 | 29 | 19 | 18 | 18 | 13 | 31 | 100 | 177 |
| 6 | 195 | 229 | 134 | 52 | 18 | 14 | 14 | 14 | 12 | 23 | 91 | 163 |
| 7 | 226 | 338 | 174 | 69 | 24 | 17 | 20 | 20 | 17 | 29 | 91 | 165 |
| 8 | 299 | 404 | 186 | 62 | 24 | 16 | 17 | 15 | 13 | 23 | 84 | 184 |
| 101 | 229 | 249 | 176 | 75 | 25 | 15 | 17 | 14 | 16 | 30 | 97 | 149 |
| 102 | 217 | 210 | 137 | 75 | 24 | 16 | 17 | 13 | 14 | 30 | 93 | 167 |
| 201 | 237 | 257 | 148 | 57 | 24 | 17 | 19 | 17 | 21 | 26 | 87 | 169 |
| 202 | 228 | 342 | 160 | 72 | 30 | 19 | 21 | 19 | 22 | 30 | 113 | 172 |
| 301 | 175 | 111 | 148 | 71 | 20 | 17 | 14 | 15 | 20 | 23 | 87 | 170 |
| 302 | 242 | 283 | 126 | 50 | 24 | 19 | 17 | 13 | 18 | 28 | 86 | 191 |
| 303 | 195 | 217 | 153 | 49 | 19 | 16 | 17 | 14 | 14 | 21 | 68 | 176 |
| 304 | 139 | 139 | 95 | 50 | 24 | 15 | 12 | 11 | 13 | 17 | 69 | 141 |
| 308 | 101 | 181 | 92 | 63 | 20 | 18 | 17 | 13 | 21 | 23 | 56 | 130 |
| 309 | 133 | 151 | 133 | 39 | 27 | 22 | 15 | 15 | 16 | 21 | 79 | 156 |
| 501 | 166 | 174 | 139 | 56 | 22 | 15 | 16 | 14 | 10 | 20 | 87 | 181 |
| 502 | 122 | 135 | 141 | 42 | 18 | 16 | 18 | 11 | 16 | 20 | 69 | 142 |
| 503 | 173 | 210 | 154 | 58 | 22 | 19 | 12 | 13 | 13 | 19 | 75 | 144 |

*Underlined values connote normality.

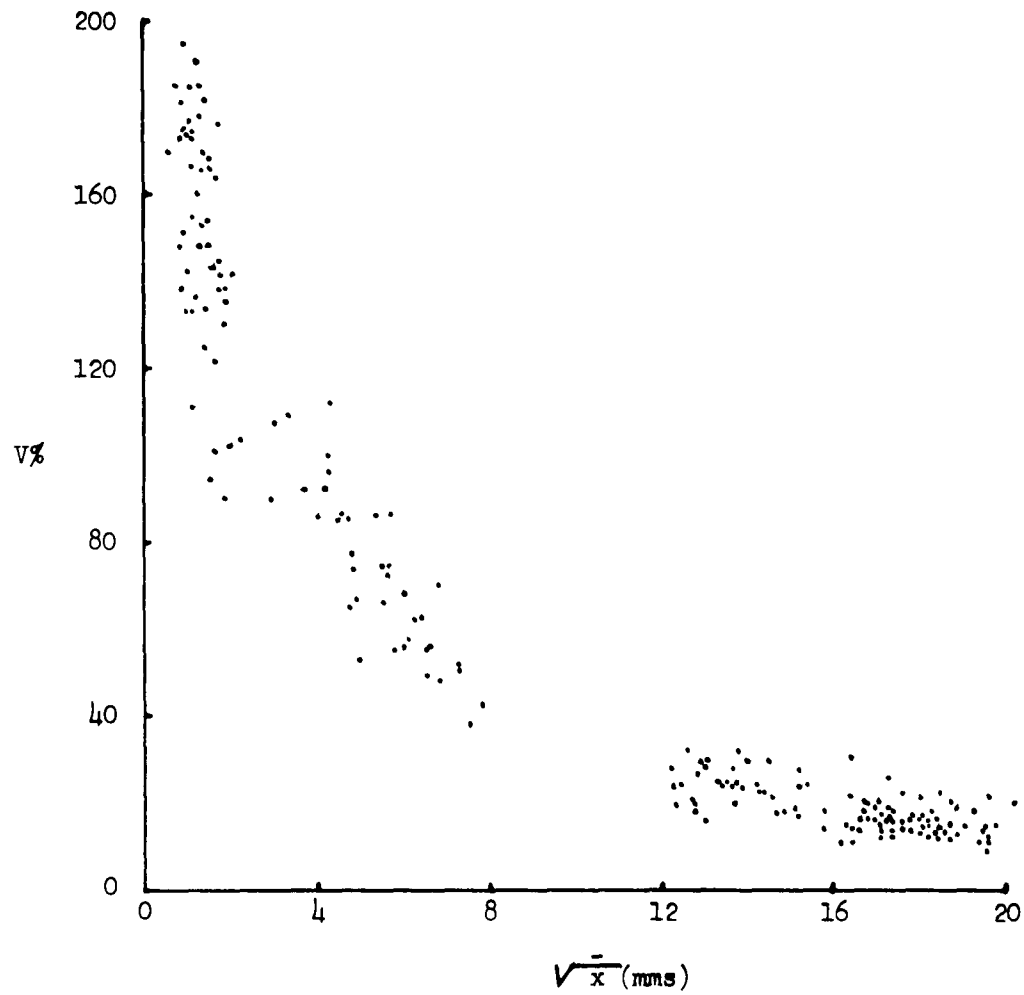



Figure 6.

Comparison Between the Coefficient of Variation (%) and the Mean of the Square Roots of the Monthly Rainfall (mm).

TABLE Va

Summary of Results and Calculated Ranges for August Totals of Rainfall

At the Chosen Twenty Stations

| Stn. | Res. | No. Yrs. | Mean | 50% range | 80% range | 90% range | 99% range | Observed Max. | Observed Min. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | N | 31 | 213 | 156-278 (52) | 112-346 (81) | 90-388 (97) | 44-511 | 597 | 104 |
| 3 | N | 31 | 228 | 174-289 (48) | 130-353 (71) | 106-396 (90) | 58-511 | 412 | 102 |
| 4 | N | 30 | 282 | 216-357 (50) | 164-433 (90) | 137-480 (90) | 77-615 | 569 | 105 |
| 5 | N | 33 | 324 | 250-408 (42) | 190-493 (85) | 159-548 (94) | 90-702 | 782 | 168 |
| 6 | N | 34 | 320 | 262-384 (50) | 213-449 (85) | 185-493 (88) | 125-605 | 602 | 163 |
| 7 | N | 47 | 289 | 216-372 (49) | 156-462 (81) | 128-515 (89) | 64-676 | 632 | 82 |
| 8 | N | 44 | 299 | 243-361 (48) | 196-424 (82) | 169-467 (91) | 112-576 | 513 | 122 |
| 101 | N | 33 | 331 | 272-396 (45) | 225-458 (88) | 199-497 (94) | 137-610 | 571 | 150 |
| 102 | N | 33 | 292 | 243-346 (42) | 204-396 (76) | 182-428 (91) | 130-520 | 483 | 174 |
| 201 | N | 46 | 289 | 228-357 (46) | 177-430 (85) | 149-475 (91) | 90-600 | 490 | 102 |
| 202 | N | 47 | 250 | 190-317 (40) | 144-384 (83) | 119-428 (91) | 66-552 | 496 | 88 |
| 301 | N | 11 | 320 | 260-385 (36) | 213-449 (91) | 185-493 (91) | 125-605 | 448 | 163 |
| 302 | N | 23 | 272 | 228-320 (61) | 188-372 (78) | 166-404 (87) | 117-493 | 419 | 132 |
| 303 | - | 25 | 250 | 204-299 (68) | 169-346 (84) | 149-376 (88) | 102-462 | 400 | 87 |
| 304 | N | 15 | 269 | 234-306 (60) | 202-346 (73) | 185-369 (87) | 144-433 | 382 | 165 |
| 308 | N | 20 | 306 | 256-361 (65) | 210-416 (85) | 188-454 (85) | 135-548 | 567 | 181 |
| 309 | N | 11 | 335 | 269-408 (45) | 216-480 (82) | 188-524 (100) | 123-650 | 503 | 190 |
| 501 | N | 31 | 324 | 266-388 (48) | 219-449 (81) | 172-488 (94) | 132-600 | 472 | 160 |
| 502 | N | 18 | 262 | 225-299 (56) | 193-342 (83) | 174-369 (94) | 135-433 | 430 | 190 |
| 503 | N | 33 | 339 | 286-396 (36) | 240-454 (85) | 213-493 (94) | 156-590 | 587 | 172 |

TABLE Vb

Summary of Results and Calculated Ranges for October Totals of Rainfall

At the Chosen Twenty Stations

| Stn. | Res. | No. Yrs. | Mean | 50% range | 80% range | 90% range | 99% range | Observed Max. | Observed Min. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | N | 31 | 154 | 108-207 (52) | 65-262 (81) | 56-299 (90) | 22-104 | 376 | 33 |
| 3 | N | 31 | 169 | 114-234 (45) | 72-306 (77) | 53-350 (90) | 16-484 | 371 | 42 |
| 4 | N | 30 | 180 | 125-243 (47) | 85-310 (80) | 64-353 (93) | 24-480 | 432 | 41 |
| 5 | N | 33 | 188 | 117-276 (48) | 67-369 (82) | 43-433 (94) | 7-615 | 476 | 13 |
| 6 | N | 34 | 199 | 142-266 (47) | 98-335 (82) | 75-380 (94) | 31-511 | 388 | 36 |
| 7 | N | 47 | 169 | 110-240 (55) | 65-320 (85) | 46-369 (89) | 10-520 | 552 | 23 |
| 8 | N | 44 | 188 | 135-250 (43) | 96-310 (84) | 74-353 (95) | 32-471 | 502 | 62 |
| 101 | N | 33 | 210 | 135-303 (52) | 81-400 (82) | 55-467 (88) | 12-655 | 665 | 41 |
| 102 | N | 33 | 196 | 125-282 (52) | 74-376 (85) | 49-441 (91) | 10-615 | 528 | 11 |
| 201 | N | 46 | 296 | 202-408 (50) | 130-529 (78) | 96-605 (91) | 31-820 | 743 | 97 |
| 202 | - | 47 | 266 | 169-384 (60) | 100-511 (79) | 69-590 (85) | 14-835 | 731 | 28 |
| 301 | N | 11 | 240 | 174-319 (27) | 121-400 (91) | 96-449 (100) | 42-600 | 382 | 103 |
| 302 | N | 23 | 149 | 98-210 (43) | 61-276 (83) | 44-317 (91) | 12-441 | 336 | 20 |
| 303 | N | 25 | 159 | 117-207 (44) | 83-260 (80) | 67-289 (96) | 31-384 | 280 | 48 |
| 304 | N | 15 | 169 | 132-210 (40) | 104-250 (87) | 88-276 (93) | 53-350 | 264 | 74 |
| 308 | - | 20 | 237 | 172-313 (20) | 119-396 (95) | 94-445 (95) | 41-595 | 382 | 80 |
| 309 | N | 11 | 324 | 240-420 (36) | 172-524 (82) | 139-586 (91) | 67-773 | 482 | 118 |
| 501 | N | 31 | 188 | 139-243 (48) | 102-299 (77) | 83-335 (90) | 42-437 | 343 | 61 |
| 502 | N | 18 | 161 | 122-207 (55) | 90-253 (78) | 74-282 (94) | 38-369 | 351 | 77 |
| 503 | N | 33 | 216 | 164-276 (39) | 123-335 (91) | 105-369 (94) | 56-480 | 335 | 66 |

Special Considerations

(a) Estimation of number of zeroes

There is a difficulty arising from the use of the simple square root normal distribution when the coefficient of variation, V, is high, above about 50, this is the problem of negative values. For example, if V is 100, then a deviation of over 1.0 $\sigma$ will give a negative calculated rainfall, and such a deviation has about a one in six chance of occurrence. Although this is a theoretical argument against the method, it need not cause trouble in practice.

A logical approach to the calculation of the number of zeroes appears to be as follows:
using whole millimeters, a reading of up to 0.49 will be counted as 0; this has a square root of 0.7, so that any value of 0.7 or less will be the same as 0 rainfall.

Thus, if $\bar{x}$ = 2.2 and $\sigma_x$ = 2.0, a deviation of more than -0.75 $\sigma_x$ will give zero untransformed values since:

$$(2.2 - 0.7) = 2.0 \times (0.75)$$

Then, the number of zeroes becomes 22.7% of the number of observations.

(b) Likely errors

It is sometimes possible to identify likely errors in the original data by means of deduction from the analysis, for example:

Station 1, Month 5 has a rainfall in 1934 such as is likely only once in 200 years, namely 574 mm. In month 6 in the same

year the rainfall is again given as 574 mm, thus suggesting a clerical error.

(c) Rapid calculation of mean square root

It appears that as the mean monthly value increases the square root of this number more closely approaches the mean of the square root values. The graph of this relationship, using most of the 240 months, is shown in Figure 7 and it is seen that for values of the mean above about 100 mm the relationship can be used to estimate the new square root mean with sufficient accuracy.

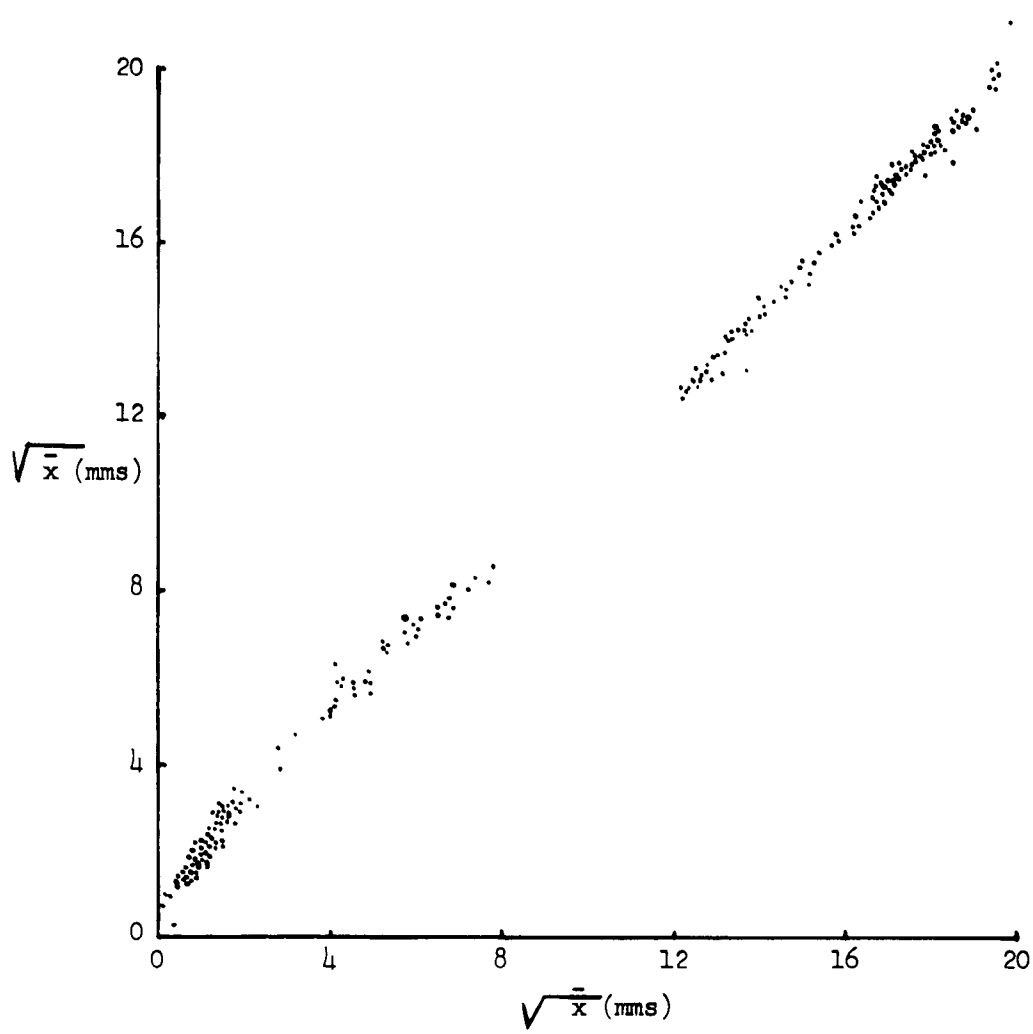



Figure 7.

Comparison Between the Square Root of the Mean Monthly Rainfall and the Mean of the Square Roots of the Monthly Values.

C. Meso-Scale Rainfall Analysis

Using a network of closely spaced rain gages, an attempt was made to determine the meso-scale pattern of rainfall and the meso-scale systems which produced the rainfall.

In any analysis, the data accuracy is suspect. In this region the rainfall is measured once a day at approximately 7 A.M. The reports are phoned into a central office where they are compiled daily. In such a system all the inherent errors of the rain gage are present. Also the observer is not a professional weather man. Many of the gages are neither properly exposed nor maintained. The data have been compiled and some of them copied by hand more than once. There are certain to be errors in these data. However, it is believed to be usable, if the analyst does not concern himself with the hundredth figure, or even the tenths figure. If he is willing to accept the viewpoint that a report of 4.36 inches represents considerably more rainfall than a report of 0.58 inches, an analysis can be prepared. In general the differences from station to station are such as to indicate that one station had a heavy rainfall while another had little or none.

Another problem is that there is no indication of the time of day when the rain fell. Also the data do not indicate the number of times it rained during the 24 hour period to amass the total. The duration of each rainfall is unknown.

In an effort to determine the meso-scale systems some assumption needs to be made as a starting point. After scanning some of the maps with daily rainfall plotted, it came apparent that a cluster of stations

had an inch or more of rain while many others had only small fractions of an inch. With a feeling that only the stronger meso-systems could be identified, the assumption was made, and used, that the area enclosed by the one inch isohyet represented one or more meso-systems. Although it is known that one cumulus cell in the tropics may precipitate several inches, say eight, upon one rain gage, the general concept used in analyzing these maps is that several inches of rainfall is caused by more than one meso-system. The small amounts are assumed to be from weak systems or small individual cells. These assumptions were used in the analysis presented in this report. As the investigation continues, better concepts may evolve. It may be that the rainy season will need a different criterion from the dry season. Selected cases will be discussed.

Case 1. On June 14, 1960, there were two well defined rain areas within the data coverage. These areas are shown in Figure 8. Each of these represents a meso-scale system. System A as enclosed by the one inch isohyet is about 5 miles wide and 8 miles long, with a total area of about 36 square miles. The individual system is estimated to be almost circular in shape and of 5 miles diameter. It was moving either north or south to give the oblong pattern. Small amounts of rain fell outside of the one inch isohyet, about 6 miles to the north and 3 miles to the south. East-west did not have enough data to define the edge of the rainfall area.

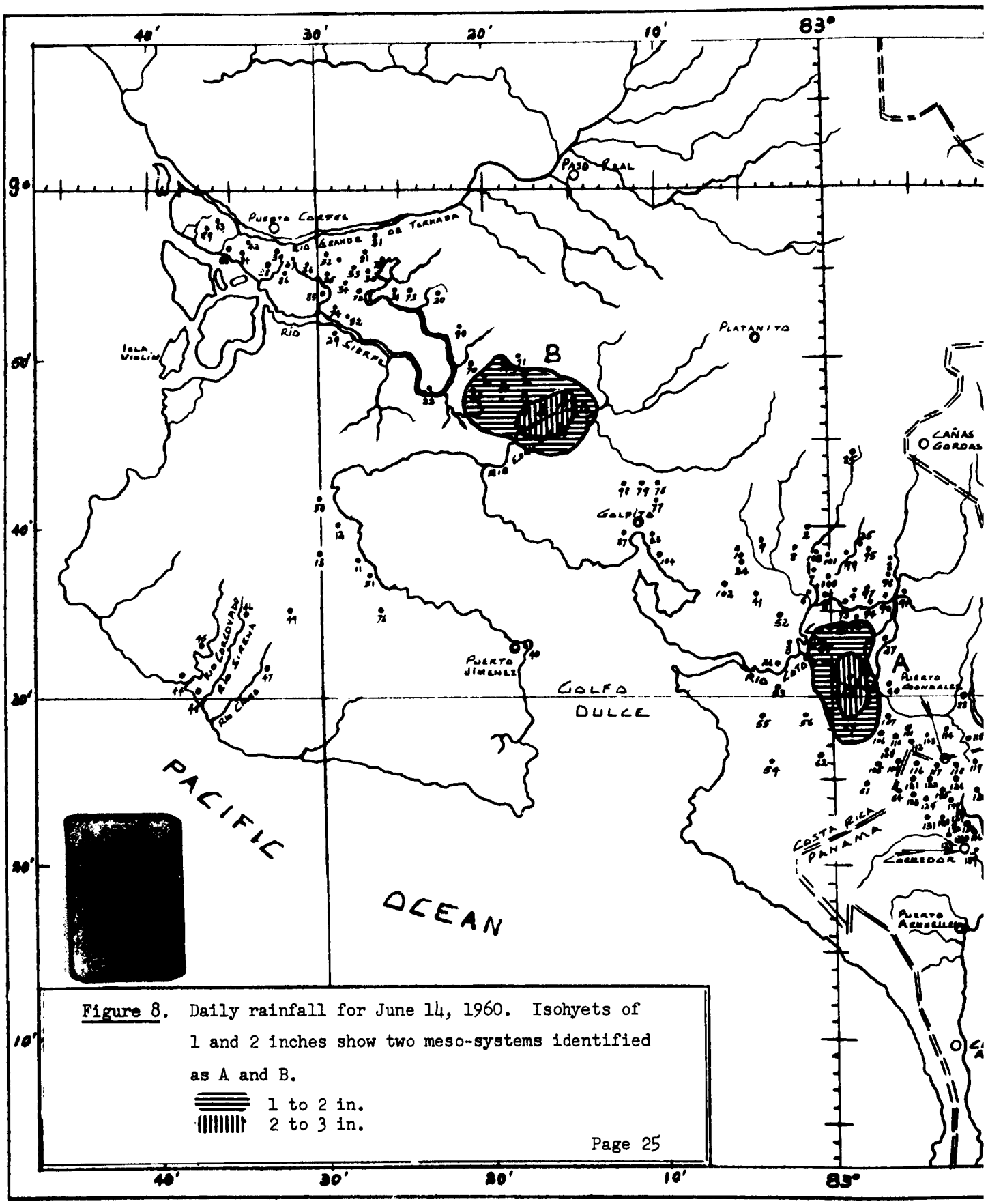
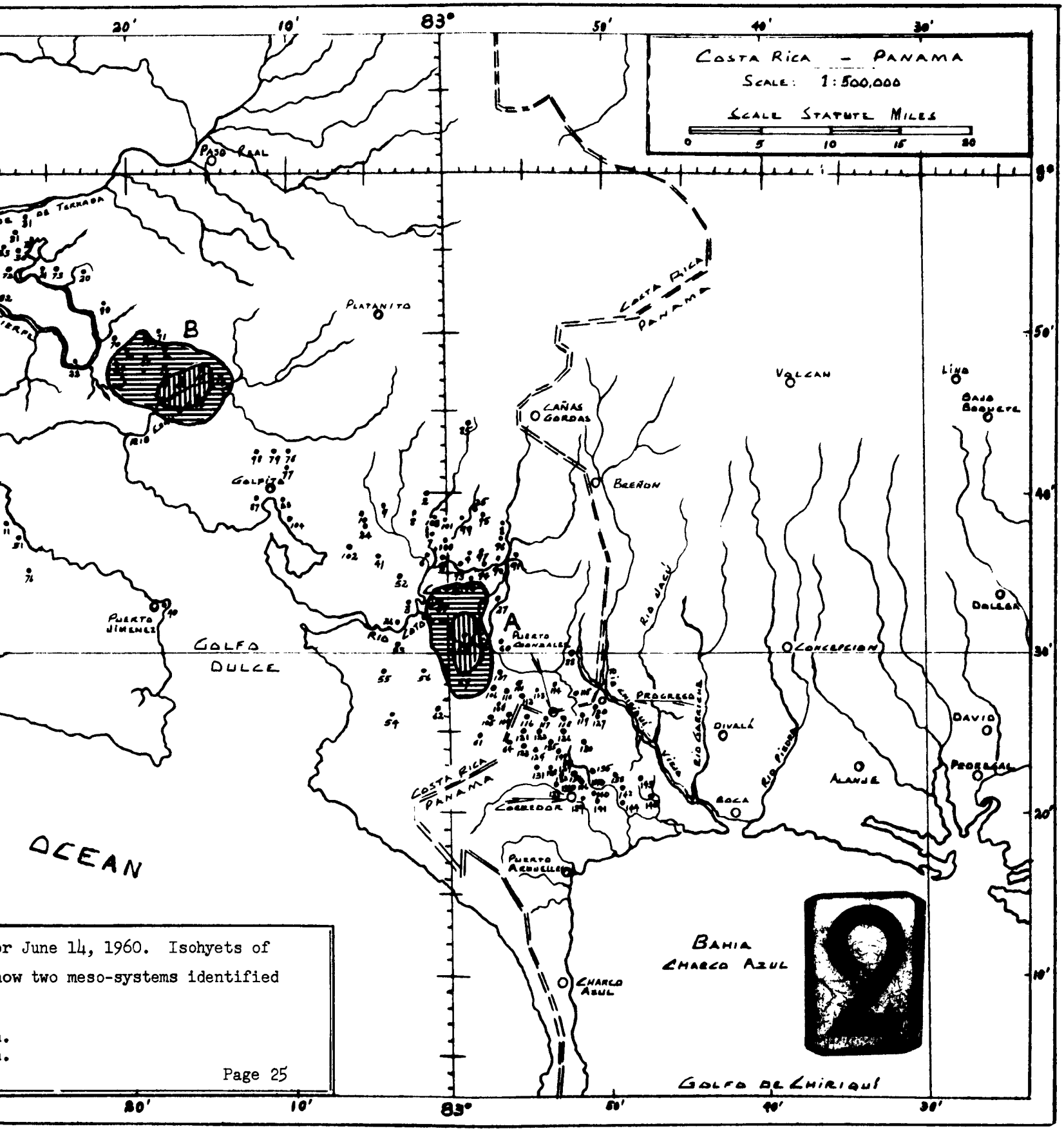



Figure 8. Daily rainfall for June 14, 1960. Isohyets of 1 and 2 inches show two meso-systems identified as A and B.

1 to 2 in.
2 to 3 in.




...r June 14, 1960. Isohyets of
...ow two meso-systems identified

...

...

Meso-system B is not as uniquely defined by the data, but it was operating as a separate system from system A. System B is larger in area and caused more rainfall.

Case 2. On July 14, 1956, there were several well-separated rainfall areas. The meso-systems were small, being of the order of 4 mile diameter. Also only two stations reported as much as two inches of rain. The analysis is shown in Figure 9.

Meso-system A and B are weak and may be the combined effect of weak systems rather than the individual systems shown. There was scattered rainfall, mostly less than three-tenths inch all around these systems.

Meso-system C was stronger, but the data do not define it. This system, along with A and B, does not appear to move, nor be a strong system.

Meso-system D unfortunately is not well defined by the data. This rainfall area is surely the combined effect of two or maybe three systems. The northeast edge of these systems is well defined with eight stations reporting no rain between system D and system E.

Systems E and F are not sufficiently in the data to give any information.

Case 3. On July 5, 1956, meso-systems were active and analyzed in Figure 10. Systems A and E were on the edge of the data. System D has the same characteristics as discussed in cases 1 and 2. It seems to have little movement.

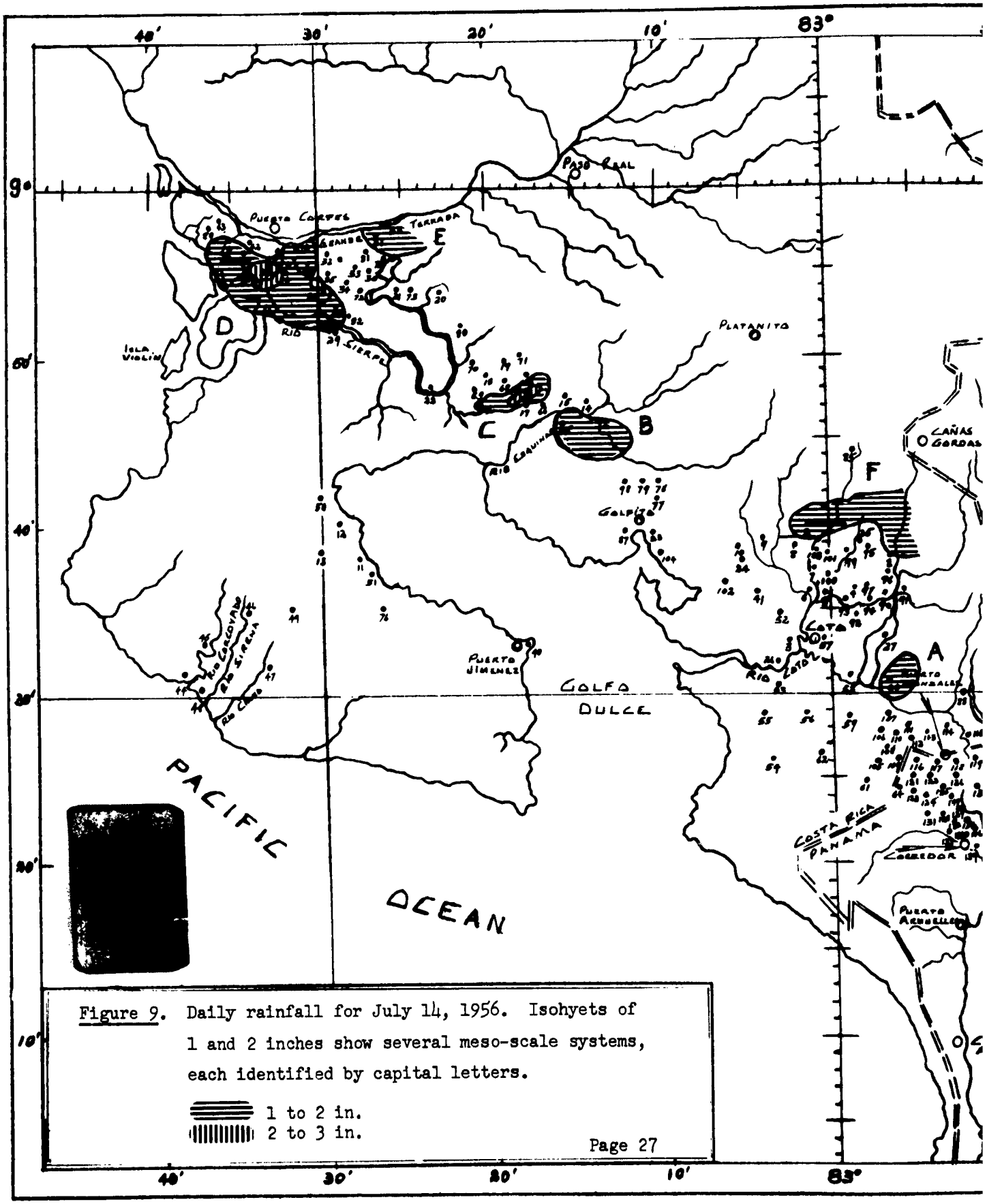
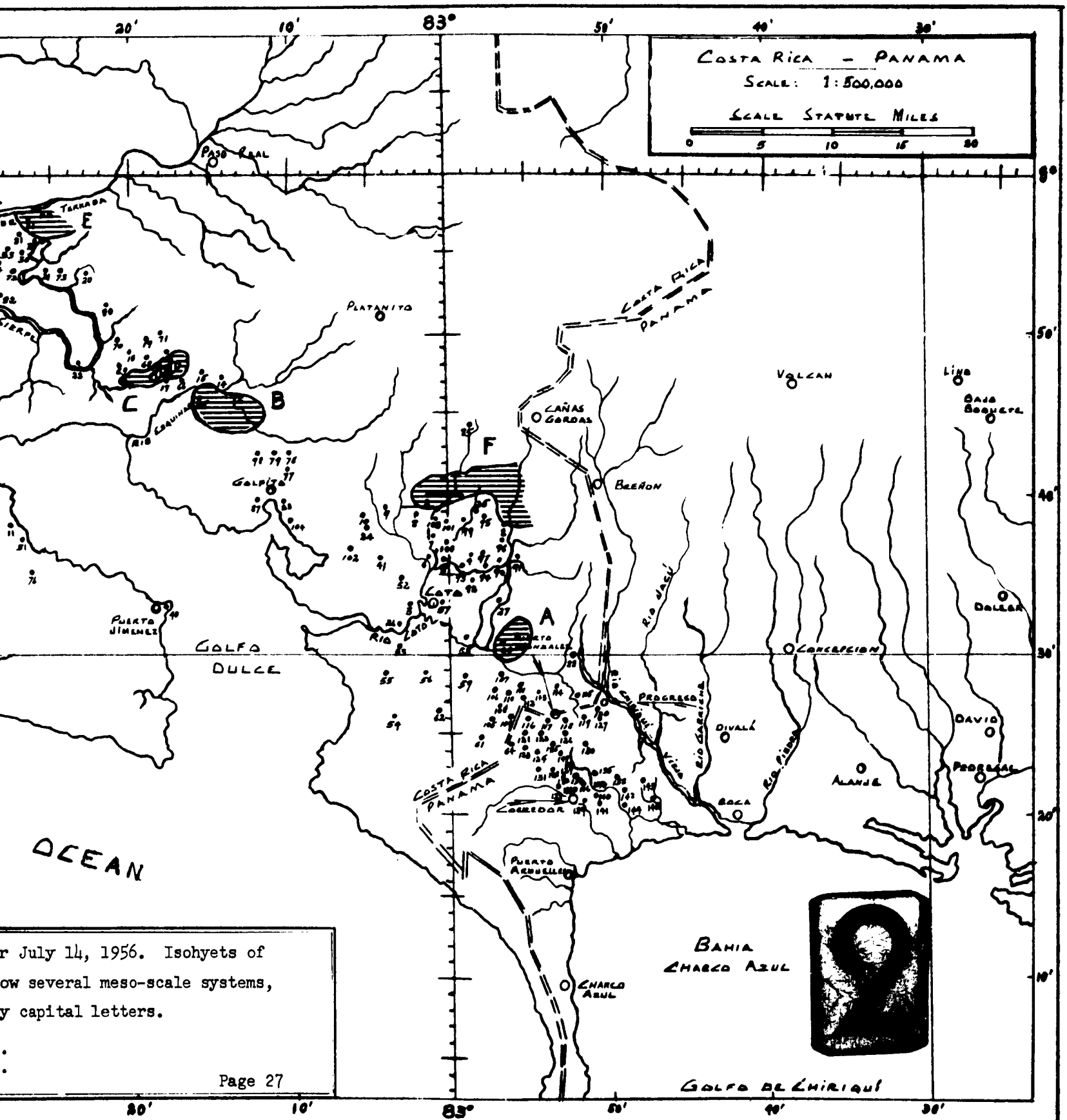



Figure 9. Daily rainfall for July 14, 1956. Isohyets of 1 and 2 inches show several meso-scale systems, each identified by capital letters.

1 to 2 in.
2 to 3 in.




r July 14, 1956. Isohyets of
ow several meso-scale systems,
y capital letters.

Meso-systems B and C are the most interesting of this day. This is a case of two systems in the same area. They may have occurred simultaneously, but the best estimate is that they were separated in time. This rain area shows two separate maximum rainfall centers. The pattern of the one inch isohyet is the combination of the two meso-systems.

Crow and Cobb,* using radar and cloud photographs have identified an individual cell size of about 1½ miles in diameter. This being the case, then these meso-systems must be a cluster of cells. Crow and Cobb indicated that the cells were found in clusters. They identified the life of a cell to be 20 to 25 minutes. Using this information and the data presented, the following is deducted. The meso-scale system consists of a cluster of cells. This system causes heavy rainfall in restricted areas. Scattered light rainfall over adjacent areas is caused by cells, many of which would represent the break-up of the system.

The same type of analysis has been attempted using monthly totals. At this time no results are available, but some of the patterns are interesting. There is a large variance of rainfall between stations.

*Loren W. Crow and Glen Cobb, "Life Cycles of Tropical Cumulus in Southwest Panama." Final Report NSF Contract C-184, Sept., 1962.

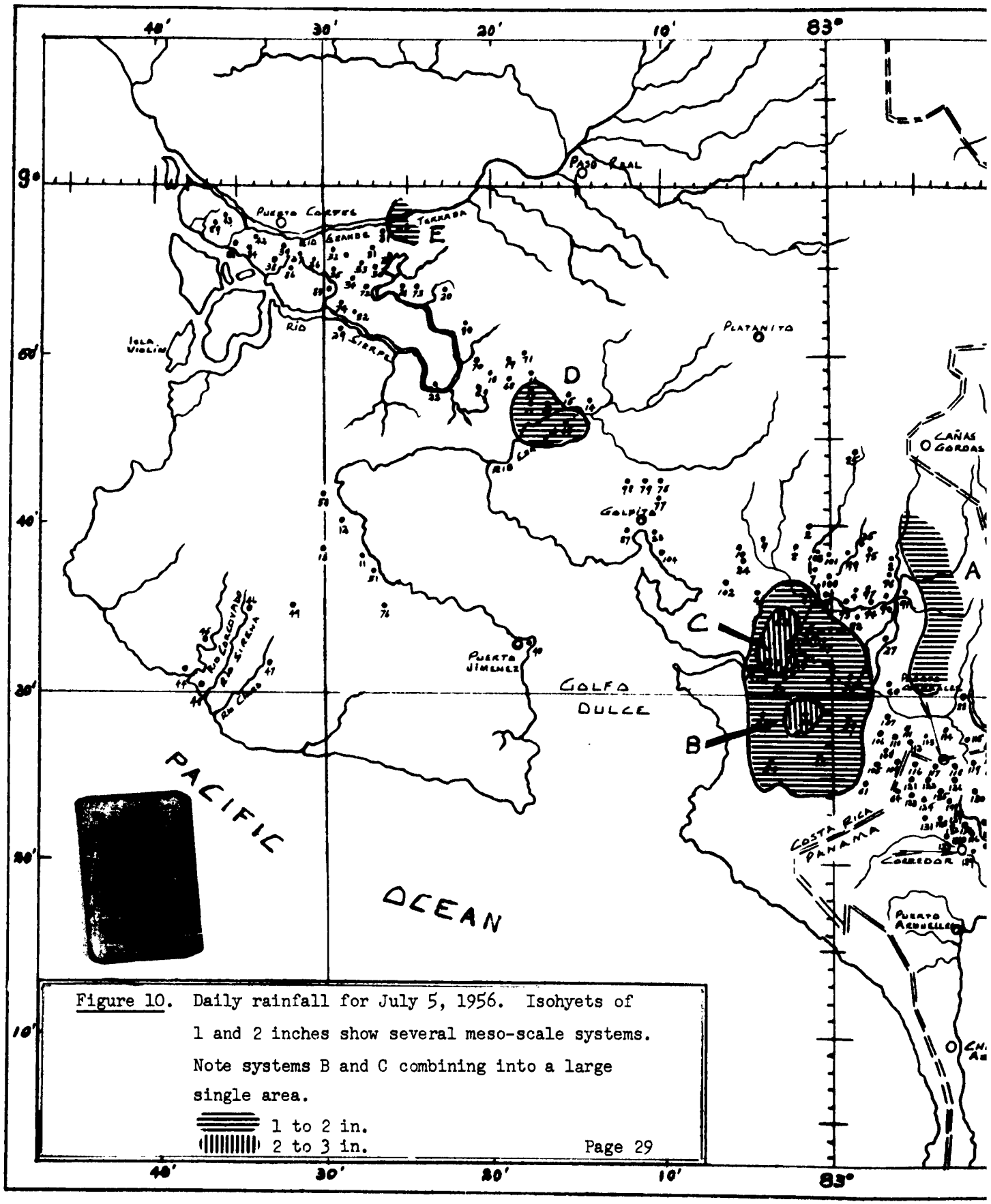
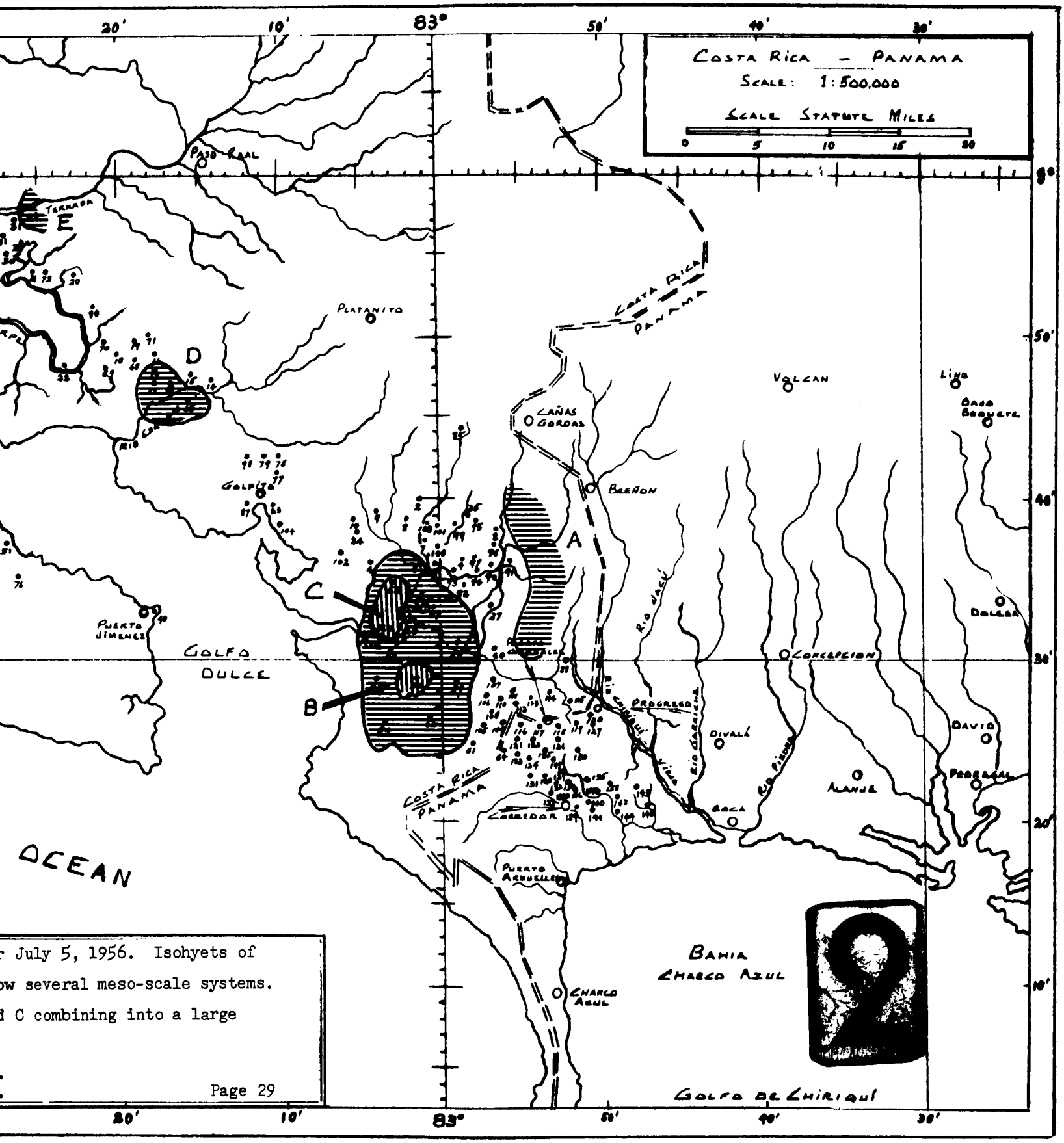



Figure 10. Daily rainfall for July 5, 1956. Isohyets of 1 and 2 inches show several meso-scale systems. Note systems B and C combining into a large single area.

1 to 2 in.
2 to 3 in.




r July 5, 1956. Isohyets of
ow several meso-scale systems.
d C combining into a large

## CONCLUSIONS

The annual and monthly rainfall values for stations in western El Salvador were shown to be tractable to the same pattern of statistical analysis as had been proved satisfactory in the African Tropics. The degree of success was most hopeful, and it augurs well for the future analysis.

The analysis of the daily rainfall maps was interesting. The fact that the areal variations of rainfall could be shown so well was encouraging. The one inch isohyet was used to delineate the area effected by a meso-scale system. To date this procedure has been successful.

## PROGRAM FOR NEXT PERIOD

During the next period, it is planned:

a. To expand the areal coverage of the statistical analysis, especially into Honduras and British Honduras.

b. To continue the analysis of daily rainfall data in the Golfito, Puerto Armuelles area. Also the monthly rainfall areal distribution will be investigated.

c. To start the analysis of daily rainfall data along the Honduras -Guatemala area and the La Ceiba, Honduras area. The comparison of these almost parallel river valleys should be interesting.

## PERSONNEL

The following personnel were engaged during this quarter:

| Name | Date Started | Date Ended | Fraction | Total Hours |
|---|---|---|---|---|
| Matthew Bastardi<br>Student Assistant | Nov. 1 | Dec. 31 | Hourly rate | 71½ |
| Daniel J. Gramatges<br>Tech. Assistant | Oct. 1 | Dec. 31 | Full | 520 |
| John F. Griffiths<br>Asst. Professor | Sept.1<br>Dec. 1 | Nov. 30<br>Dec. 31 | ½<br>¼ | 260<br>40 |
| Walter K. Henry<br>Asst. Professor | Sept.1 | Dec.31 | ¼ | 170 |
| Allen B. Lee<br>Student Assistant | Dec. 1 | Dec. 31 | Hourly rate | 12½ |
| Dale F. Leipper*<br>Department Head | Sept.1 | Dec. 31 | | |
| Stephen Kent Rinard<br>Student Assistant | Dec. 1 | Dec. 31 | Hourly rate | 10½ |
| David R. Smith<br>Student Assistant | Nov. 1 | Dec. 31 | Hourly rate | 69 |
| Judith E. Stradinger<br>Sec - Computer | Sept. 1 | Dec. 31 | Full | 680 |

*Dr. Dale F. Leipper is Head of the Department of Oceanography and Meteorology, and Project Supervisor, at no cost to the project. He gives general guidelines, but the administration and operation of the project is accomplished by Mr. Henry in addition to his research functions.

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John F. Griffiths & Walter K. Henry

Report No. 2, 2nd Quarterly Report - 1 Sept. 1962 to 31 Dec. 1962. 32 pp. Signal Corps Contract DA-36-039 SC-89202

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